RISK ANALYSIS METHODOLOGY
APPENDIX H

Estimating Hydrologic Risk

U.S. Bureau of Reclamation
Technical Service Center
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Risk Analysis Methodology - Appendix H
Estimating Hydrologic Risk
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I. Purpose

The purpose of this toolbox is to give risk analysis participants and Senior Engineers guidance on processes to follow and issues to consider, in addition to those already provided in the Methodology, when developing estimates of risk for hydrologic loading conditions. This guidance will be revised or supplemented as necessary by the staff involved in probabilistic flood estimation in the Technical Service Center as they develop new processes and recommendations on developing and using flood frequency information for risk analyses.

II. Hydrologic Load Issues

When performing a baseline risk analysis or assessing the risk of a particular dam for a Comprehensive Facility Review (CFR), the participants should gather the available documentation on the most recent flood studies, flood routing studies, and/or flood frequency analyses. This information can often be found in the SEED Data Books, Dam Safety Information System (DSIS), or within the files of the Waterways and Concrete Dams Group (D-8130) or the Flood Hydrology Group (D-8530). Contacting a team member from any of these groups can help in the search for the necessary information.

Once this data is located and reviewed, the possible courses of action for estimating hydrologic risk can be determined by comparing the available data to the following scenarios:

> A. If the latest documented flood routing studies show the dam can safely pass the current estimation of the Probable Maximum Flood (PMF) or at least 95 percent of the PMF, the risk posed by dam failure from overtopping during extreme flood events is probably too small to be a concern and further evaluation of the risk from this failure mode is probably not required. The CFR Report or risk analysis report should conclude that the risk from flood events causing dam failure by overtopping is less than Reclamation's public protection guidelines with diminished justification for taking additional actions to further reduce the risk. Other flood-related failure modes besides overtopping should still be considered on a case-by-case basis, and these are described below in Section III.
>
> B. If the latest flood routing studies show the dam is overtopped by a flood smaller than 95 percent of the PMF, a peer-reviewed preliminary flood frequency analysis (FFA) should be obtained. Guidelines for how to use and interpret the FFA are provided in Attachment 1. Contact the Flood Hydrology Group (D-8530) to see if an FFA already exists or if a new one needs to be prepared. If a new FFA is needed, a request for this analysis should be made well in advance of the risk analysis or CFR initial meeting to

allow the appropriate flood specialists sufficient time to schedule the resources, perform the analyses, document the results, and have the document peer-reviewed prior to the time the FFA is to be used.

1. If the total discharge capacity of the spillway and outlet works is greater than the estimated peak inflow associated with the flood having a probability of 0.0001 (return period of 10,000 years) using the middle curve from the FFA, the probability of failure from overtopping will be lower than Reclamation's Tier 2 guideline values. The estimated risk from such an event will depend upon the potential for incremental loss of life (the loss of life resulting from the overtopping failure of the dam minus the loss of life expected from the flood event itself without dam failure). If the incremental loss of life could be high, then Reclamation's Tier 1 guidelines may be exceeded, even with the low probability of failure. In this case, the FFA will need to be revised by extrapolating the frequency curves beyond a return period of 10,000 years. This will require the experience, judgement, and additional efforts of flood specialists in the Flood Hydrology Group.

The following example is provided to illustrate this scenario. The hypothetical Ono Dam (an embankment dam with an ungated overflow spillway) has a spillway discharge capacity of 24,000 ft^3/s at the design maximum reservoir elevation and a discharge capacity of 30,000 ft^3/s when the reservoir is at the crest of the dam. The outlet works at Ono Dam can pass an additional 2,000 ft^3/s. The PMF developed for Ono Dam results in the dam being overtopped by maximum of 2.5 feet for a total duration of 12 hours. An FFA was prepared for use in the risk analysis of this dam and it shows the peak inflow of the flood having a return period of 10,000 years is approximately 25,000 ft^3/s. Based on this data, the risk analysis participants can determine that the probability of failure from overtopping is less than 0.0001 and Reclamation's Tier 2 guidelines are not exceeded.

A few miles downstream from Ono Dam is a city having a population at risk of 10,000 people in the dam failure flood plain. The risk analysis participants determine that failure of the dam from overtopping will result in "Medium" flood severity in the city, the inhabitants will have more than one hour of warning, and the flood severity understanding will most likely be "precise." This results in a fatality rate of about 0.01 and a potential loss of life estimate of about 100. When this estimate is multiplied by the estimated probability of failure of something less than 0.0001, the resulting estimate of risk may approach a value as high as 0.01, which exceeds Reclamation's Tier 1 guidelines, but it may be considerably less. At this point, the risk analysis team should recommend that specialists from the Flood Hydrology Group prepare additional flood studies to refine and extrapolate the FFA data. This additional information will allow a better definition of the risk from overtopping failure in the risk analysis.

If the population at risk downstream from Ono Dam was only 100 and the estimate of loss of life was about 1, the risk could be estimated to be well below the Reclamation's Tier 1 guideline value of 0.001. Additional flood studies and refinements to the FFA would not be necessary.

2. If the total discharge capacity of the spillway and outlet works is less than the estimate of the peak flood inflow having a probability of 0.0001 (return period of 10,000 years) as characterized by the middle curve of the FFA, then the hydrologic risk should be fully addressed in the risk analysis using the processes described in the text of the Methodology. The Senior Engineer for the CFR may consider recommending an additional risk analysis be performed to address the hydrologic issues. Each dam that falls within this scenario will need to be analyzed on a case-by-case basis by the risk analysis team or the Senior Engineer. The key issue to consider will likely be the volume of the flood(s), so working with the flood and flood routing specialists to portray the flood volume information as clearly as possible in a probabilistic manner will be necessary. Issues involving flood volumes from one single large flood event versus the volume generated from several smaller back-to-back storm events may also need to be addressed.

Another example is provided to illustrate this scenario. The hypothetical Oyes Dam (an embankment dam with an ungated spillway having a morning-glory intake) has a spillway discharge capacity of 10,000 ft^3/s at the design maximum reservoir elevation and a discharge capacity of 12,000 ft^3/s when the reservoir is at the crest of the dam. The outlet works at Oyes Dam can pass an additional 4,000 ft^3/s. The reservoir for Oyes Dam has a dedicated flood control pool of 95,000 acre-feet and a surcharge pool of 70,000 acre-feet. The PMF developed for Oyes Dam results in the dam being overtopped by maximum of 3 feet for a total duration of 18 hours. An FFA was prepared for use in the risk analysis and it shows the peak inflow of the flood having a return period of 10,000 years is approximately 25,000 ft^3/s. Based on this data, the risk analysis participants can see that the probability of failure from overtopping may be greater than 0.0001 (exceeding Reclamation's Tier 2 guidelines), but this cannot be determined with certainty because of the large flood control and surcharge storage volumes available within the reservoir. At this point, the risk analysis team should recommend that specialists from the Flood Hydrology Group prepare additional flood studies that provide probabilistic flood hydrographs. These hydrographs can then be routed and the results used to estimate the likelihood and risk of overtopping for use in the risk analysis.

As with the other flood scenarios described previously, other flood-related failure modes besides overtopping should still be considered on a case-by-case basis, and these are described below in Section III.

III. Hydrologic Response Issues

For embankment dams, the primary failure mode considered for flood loads is failure of the dam from overtopping with erosion of the downstream toe and face of the dam and subsequent collapse of the dam crest. However, other failure modes that should be considered in the risk analysis or CFR include:

- failure of the spillway chute or stilling basin from erosion, cavitation, or overtopping during high discharges,
- mechanical failure of the spillway gates or hoists (if applicable),
- seepage through the top portion of the dam above the impervious core, or
- increased likelihood of seepage and piping through the dam or foundation, especially if this portion of the dam or foundation has not been exposed to high reservoir levels before (essentially a first filling situation).

A sample event tree that demonstrates one way of evaluating different hydrologic failure modes is provided in Attachment 2.

Depending on the material properties of the dam and foundation, the mechanism for overtopping failure of an embankment dam is generally erosion that initiates at the downstream toe of the dam. Headcutting proceeds upstream along the downstream face of the dam until the crest becomes unstable and topples into the hole created. It should be noted that breach of the dam from overtopping is not a certainty. The time required to breach the dam crest after initiation of overtopping flows can be a few hours or more, as discussed in Appendix N of the Methodology, titled Prediction of Embankment Dam Breach Parameters. This Appendix provides guidance on how to estimate the breach parameters, which is valuable information when considering the likelihood of failure from overtopping, warning time estimates, and downstream loss of life issues.

Similarly, the other potential failure modes associated with flooding described above for embankment dams should take considerable time to occur with the exception of mechanical failure of the spillway gates. This failure mode could quickly release large discharges through the spillway without warning that may threaten those people along the channel immediately downstream of the dam. The risk analysis should consider the potential range of flows through the failed gate(s) and compare these values to the discharge capacity of the downstream channel and the potential inundation of downstream populations when estimating the consequences from the gate failure.

Guidance on the risk estimation processes for the failure modes associated with seepage and piping of the dam or foundation during high reservoir levels is provided in Appendix E of the Methodology - Estimating Risk of Internal Erosion and Material Transport Failure Modes for Embankment Dams.

For concrete dams, the primary failure modes considered for flood loads are failure of the foundation from erosion or plucking during overtopping events or foundation instability from the increased reservoir and uplift loads. Other potential failure modes that should be considered include:

- failure of the spillway chute or stilling basin from erosion, cavitation, or overtopping during high discharges,
- mechanical failure of the spillway gates or hoists (if applicable), or
- overstressing and cracking the concrete in the dam from higher reservoir loads (a first filling situation).

Failure of concrete dams from any of these failure modes could happen suddenly and without any warning. Another toolbox is in the planning stages that will eventually provide additional guidance on estimating the likelihood of failure of concrete dams from overtopping events.

IV. Considerations on Consequences from Flood Failure Modes

The estimation of life loss resulting from the failure of a dam during flood events is dependent upon the size of the population at risk, the amount of time available for warning and evacuation prior to the arrival of the failure flood, the severity of the flood resulting from dam failure, and the understanding of the warnings and evacuation notices by the affected public. Details on the estimation of consequences are available in [1], Section IV.E. of the Methodology, and in Appendix O, Estimating Potential for Life Loss Resulting from Uncontrolled Release of Reservoir Water.

Several factors may contribute to a lower potential loss of life from flood-related failure modes compared to static or seismic failure modes:

- Populated areas downstream from dams usually receive warning of floods and spillway releases well before dam failure occurs.
- Severe weather is often detected early by radar and satellite and the media can issue warnings to the public.
- Several Reclamation dams have Early Warning Systems (EWS) installed to provide better detection of potentially threatening rainfall or runoff events.
- Even without an EWS, large flood inflows into the reservoir and subsequent spillway releases usually trigger implementation of the Emergency Action Plan by operations personnel at the dam with warnings issued to the appropriate local emergency management officials.
- Spillway discharges that begin to exceed the safe downstream channel capacity result in localized flooding, alerting the population along the river and prompting the evacuation of at least some of the downstream population at risk before larger spillway discharges or dam failure occurs.

For some dams, the downstream population at risk (PAR) from the failure of a dam during a flood event will be lower than that during sunny-day failure modes because of the potential for fewer recreational users to be present on the river or along the downstream river channel during severe weather conditions. This factor should be addressed on a case-by-case basis using available knowledge of the characteristics of the downstream flood plain from the Area Office staff.

V. Uncertainty Considerations

The primary uncertainty for hydrologic risk lies in the determination of the load probabilities. The processes for estimating flood probabilities are currently in transition from the deterministic practices of estimating the PMF to probabilistic methods of estimating flood frequencies using paleoflood data, regional and site-specific flood hydrology information, and various modeling techniques. Reclamation is still determining which technical processes are to be used to provide the best overall portrayal of the probabilities of remote flood events. As a result, preliminary flood frequency analyses should be used carefully in a risk analysis and subsequent decision-making. The technical specialists that prepared the flood frequency analysis should review the portions of the risk analysis documentation concerning hydrologic loads to ensure the flood data was used and interpreted properly.

The uncertainties associated with the response of dams to large flood events are associated with many factors, including:

- Duration of the flood. The flood may have passed before a failure mode develops or the duration may be very long making some failure modes more likely to develop.
- Effects of tailwater. High tailwater levels from the spillway and outlet discharge may inundate and protect (cushion) the toe of the dam and lessen the likelihood that overtopping flows will initiate the erosion process at the toe of the dam, or flow patterns may be significantly changed such that erosion may be more likely.
- Spillway hydraulics. The spillway may pass the flood flows exactly as designed with no failure, or the spillway may have potential problems with cavitation or subtle changes in the spillway configuration that cause undesirable flow characteristics and ultimately failure of the spillway.
- Dam materials. The materials in place on the crest and downstream face of the dam may inhibit failure from overtopping and the materials within the dam or foundation may inhibit the formation of piping failure modes.
- Spillway materials. The materials in the spillway crest, chute, and stilling basin may be very resistant to erosion or may be flawed to the point that spillway discharges could cause failure of the spillway and result in an uncontrolled release of the reservoir.
- Debris. Debris may clog the spillway and lead to premature overtopping or cause failure of the spillway gates or spillway structures.
- Attendance at the dam. Early observation of the onset of the potential failure modes may allow sufficient time to implement successful intervening actions that prevent the failure

mode from developing further. Early warnings may also be issued to local emergency management officials to reduce the potential for loss of life.

These are only a few of the potential factors that may affect the response of the dam during flood events. Each risk analysis will need to identify these types of site-specific factors that influence the response of the dam and introduce uncertainty into the results. The risk analysis participants or Senior Engineer will need to consider if additional actions (data collection, analysis, etc.) are needed to reduce the uncertainties before an appropriate decision can be made. The specific processes that should be followed to adequately portray and communicate this uncertainty are documented in Section V.B. of the Methodology, in Appendix T - Handling Uncertainty, and in Appendix R - Guidelines for Communicating Risk Information.

VI. Considerations for Decision Makers

Risk analyses performed to date for Reclamation dams have indicated that the risk from flood events is generally low because of the adequate spillway capacity provided, the low probability of the severe flood events, or the low consequences resulting from dam failure. Some dams, however, may be above large population centers where the consequences and resulting hydrologic risk still are very high (Tier 1) [2]. In some areas of the western United States, the likelihood of large storms and floods may be much higher, resulting in the dam having a high probability of failure during a flood (Tier 2). These situations will need to be addressed on a case-by-case basis with the appropriate level of detail provided in a flood study and by understanding the behavior of the dam and appurtenant structures during flood events. The uncertainties in the flood loading, response of the dam, and downstream consequences should also be clearly portrayed so the appropriate decision on the future course of action is reached. Continued emphasis on early detection of the flood, good operations and maintenance practices for the spillway and other required waterways, and well-written and exercised emergency action plans will help minimize the risk from floods.

<u>References</u>

[1] DSO-99-06, A Procedure for Estimating Loss of Life Caused by Dam Failure, prepared by Wayne Graham, September 1999.

[2] Guidelines for Achieving Public Protection in Dam Safety Decision Making, Bureau of Reclamation, April 4, 1997.

Attachment 1

TECHNICAL SERVICE CENTER
Denver, Colorado

GUIDELINES FOR INTERPRETING PRELIMINARY FLOOD FREQUENCY ANALYSIS REPORTS

VERSION 1.0
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Prepared by

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U.S. Department of the Interior
Bureau of Reclamation

RECLAMATION'S MISSION

The mission of the Bureau of Reclamation is to manage, develop and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

DEPARTMENT OF THE INTERIOR'S MISSION

The mission of the Department of Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

GUIDELINES FOR INTERPRETING
PRELIMINARY FLOOD FREQUENCY ANALYSIS REPORTS

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FIGURES

1.0 INTRODUCTION

This document provides guidelines for the interpretation of Preliminary Flood Frequency Analyses for Comprehensive Facility Reviews (CFR's) and describes the features of the Preliminary Flood Frequency Analysis. It is the second in a series of guidelines, the first of which was designed to standardize the method used to develop the Preliminary Flood Frequency Analysis (England et al., 2001). These guidelines are intended to be used by Dam Safety decision makers and technical staff within the Bureau of Reclamation. The purpose of this document is to provide general information about how the Preliminary Flood Frequency Analysis is developed and to provide guidance for interpreting Preliminary Flood Frequency Analysis results. Revisions to this document will be made as needed.

The Preliminary Flood Frequency Analysis provides information required in the CFR Process in order to gain a preliminary understanding of hydrologic hazards for Reclamation dams. The Preliminary Flood Frequency Analysis is produced based on a recommendation from the Waterways and Concrete Dams Group (D-8130) for dams that appear to have hydrologic deficiencies. The need for probabilistic flood information is a direct outgrowth of the recent emphasis on risk analysis in Reclamation's Dam Safety Program. For the majority of Reclamation dams, probabilistic hydrologic information still needs to be developed. The Preliminary Flood Frequency Analysis is a first step toward understanding probabilistic hydrologic hazards at Reclamation dams. Although CFR-level decisions can be just as important as higher level decisions, data collection and analysis are limited in scope for this project. For decisions beyond the CFR, additional information may need to be collected and analyzed to verify preliminary projections of flood frequency from the Preliminary Flood Frequency Analysis.

1.1 Structure of the Guidelines

Section 1 provides an introductory framework for this document. Section 2 describes the data used in generating the flood frequency curves and the features of the flood frequency curves. Section 3 provides a discussion of relevant issues concerning the interpretation of the flood frequency curves for use in a risk analysis.

1.2 Purpose/Definition of the Preliminary Flood Frequency Analysis

The Preliminary Flood Frequency Analysis provides preliminary flood frequency information for the CFR Process. The peak discharge frequency curve is the main product generated from the Flood Frequency Analysis and provides peak discharge estimates for return periods up to 10,000 years if paleoflood data are available and used in the analysis. The product is the result of a ten-day effort coordinated by the Flood Hydrology Group (D-8530). Staff time includes gathering historical gage data and paleoflood reconnaissance data, preparation of the flood frequency curve and report, and peer review.

2.0 FEATURES OF THE PRELIMINARY FLOOD FREQUENCY ANALYSIS

This section provides a description of the kinds of data used to develop the preliminary flood frequency curve for the CFR Process and an explanation of the components of a Preliminary Flood Frequency Analysis. Details of the method are presented in England et al. (2001).

2.1 Data Used to Develop the Preliminary Peak Discharge Frequency Curve

The preliminary peak discharge frequency curve is developed by combining data from an analysis of at-site peak discharge, regional peak discharges, and at-site and regional paleoflood data. At-site peak discharge data is often used when developing the curve; however, regional discharge data may be used if at-site peak discharge data is not available. In addition, regional peak discharge information is used along with other available discharge estimates to form an envelope curve which defines maximum peak discharge estimates that are assigned a 100- to 500-year return period for the region. At-site paleoflood data is also the preferred information source to use in the flood frequency analysis if it is available. When it is not available, regional paleoflood data may be used. Ideally, both data sets are available and can be incorporated. The preliminary peak discharge frequency curve with confidence limits is developed up to the 100-year return period using at-site and/or regional peak discharge data. Beyond the 100-year return period, the upper, middle, and lower curves are constructed based on additional information as discussed below.

2.2 Frequency Distribution and Confidence Limits

A frequency distribution is fitted to the at-site peak discharge data or regional peak discharge data to define peak discharge probabilities from the 1 to 100-year return period. The most common distribution used is the Log Pearson III (LP-III) Distribution (IACWD, 1981). A regional distribution is estimated if sufficient at-site data are unavailable. The flood frequency curve and 90% confidence interval is estimated and defined up to the 100-year return period (A on Figure 1). Commonly, the data used in the analysis include less than 100 years of record; the best curve is extrapolated up to the 100-year return period. The 90% confidence interval indicates that for a specific return period (based on the chosen distribution), there is a 90% chance that the peak discharge will fall between the upper and lower confidence limit.

2.3 Regional Data and the Envelope Curve

The regional envelope curve is drawn on a plot of peak discharge versus drainage area. This curve envelopes regional maximum peak discharge estimates from gages and miscellaneous peak discharge estimates in the region of interest in order to estimate a maximum peak discharge for a specified drainage area (Figure 2).

From the regional envelope curve, the probable range of maximum peak discharge values is determined and used to define the regional peak discharge range for the site of interest. Usually, the range is based on the value of the envelope curve and a cluster of data points below the curve. For preliminary flood frequency analyses, regional peak discharge data are defined as having return periods that range from 100 to 500 years and the range of peak discharge values as defined by the envelope curve (B on Figure 1).

2.4 Paleoflood Data

Paleoflood data provide peak discharge estimates for floods that are beyond the limits of estimates provided by gage data. The paleoflood information is defined by a probable range of peak discharge values and the return periods associated with these estimates © on Figure 1). This information is gathered at the site or in the region of interest and is determined by estimating discharges based on evidence of exceedance and/or nonexceedance of specific geologic features preserved in the geologic record over estimated time intervals. A range of discharges is usually given to account for uncertainties in the roughness coefficient and other parameters. The uncertainty in age estimates is based on the error reported from radiocarbon analyses or from pertinent literature.

2.5 The Middle Preliminary Flood Frequency Curve

The Middle Preliminary Flood Frequency Curve is defined from the 100-year to 10,000-year return period by fitting a curve from the LP-III distribution at the 100-year return period through the midpoint of the paleoflood peak discharge and return period data and extending the curve to the 10,000-year return period (D on Figure 1). This curve is constructed based on interpolation and extrapolation and simply represents one interpretation of extreme flood behavior. *This curve is not an extension of the distribution function and does not include an estimation of the statistical confidence*. If paleoflood data are not available, the middle preliminary flood frequency curve is not drawn beyond the 100-year return period.

2.6 Upper and Lower Preliminary Flood Frequency Curve Estimates

The upper and lower preliminary flood frequency curve estimates represent the range of discharge values which are possible for the data set and a specified return period. The upper curve extends to the maximum discharge from regional data at the 500-year return period or maximum paleoflood peak, whichever is larger (E on Figure 1). In the absence of paleoflood data, the upper curve is drawn to the maximum value of the regional data at the 500-year return period. The lower curve extends from a 100-year return period to a 10,000-year return period based on the LP-III model peak discharge estimate for the 100-year flood (F on Figure 1). The upper and lower frequency curves are intended to represent the range of possible peak discharge values for a flood with a given return period. The curves do not represent a measure of statistical confidence about the middle curve.

3.0 INTERPRETING THE PRELIMINARY FLOOD FREQUENCY CURVE

This section provides some general guidelines for interpreting preliminary flood frequency curves and provides answers to some frequently asked questions.

3.1 Recommended use of the Preliminary Flood Frequency Analysis

As stated in the introductory section, the Preliminary Flood Frequency Analysis uses available data and in many cases may include a large range of uncertainty. CFR-level studies are different than higher level studies because their conclusions are based on limited budget and staff time. Thus, confidence in the estimates is lower than for more detailed studies. The frequency curve is intended to be used for the CFR process or as a starting point for Issue Evaluation Risk Analyses if no other information is available and at most, up to a 10,000-year return period.

3.1.1 *Explanation of the statement on the preliminary flood frequency graph*

A typical statement included on the preliminary flood frequency graph reads: "This flood frequency relationship is based on available streamflow data and preliminary paleoflood data. These curves are not meant to be extrapolated. Refer to the report for a discussion of uncertainties." The statement expresses the reasonable scientific limitations of the data and interpretations provided in the Preliminary Flood Frequency Analysis described above. The relationships expressed on the preliminary flood frequency diagram have only been developed for return periods up to their representation on the graph. Although there is not a procedure for extending the frequency curve beyond the 10,000-year return period on the graph, dams that need information beyond the 10,000-year return period can be discussed with the Manager and appropriate staff of the Flood Hydrology Group (D-8530) to determine the scope of the problem and course of action for the specific dam.

3.1.2 *Proper use of the frequency curves on the preliminary flood frequency diagram*

When assessing risk at a site, use all of the curves on the preliminary flood frequency diagram. Up to the 100-year return period, the 90% confidence interval is intended to provide an estimate of the statistical uncertainty associated with the more frequent discharges. This means that a peak discharge value for a given return period has a 90% chance of falling within the confidence interval. The probability of the peak discharge being different than that of the mean frequency curve decreases away from the mean frequency curve in either direction. When the distance between the confidence limits is large, there is a large amount of uncertainty and thus, a wide range of peak discharge estimates associated with a given return period. When the distance between the upper and lower confidence limits is small, there is less uncertainty, and thus, a narrow range of discharge estimates for a given return period. At return periods greater than 100 years, the middle curve represents the best estimate while the upper and lower frequency curves reflect the interpreted range of possible estimates for extreme floods. These curves are interpolated and/or extrapolated using regional and paleoflood peak flow data and have no quantitative statistical connotations.

3.1.3 *How to estimate a maximum peak discharge at low probabilities when the upper frequency curve does not extend to the 10,000-year return period*

The upper frequency curve is extended only to the estimated limit of observed information. At this time, the upper frequency curve is not extended beyond the regional or paleoflood data available at the time of the analysis. The author of the Preliminary Flood Frequency Analysis will identify the "best" estimate for both regional and paleoflood data based on the available information. If this produces a level of uncertainty in which a Senior Dam Engineer cannot adequately assess the hydrologic risk, then an additional study should be performed to explicitly describe and reduce the uncertainty. This uncertainty will be resolved as more information becomes available.

3.1.4 *How to use the Preliminary Flood Frequency Analysis as a screening tool*

The Preliminary Flood Frequency Analysis is based on readily available hydrologic information. The Preliminary Flood Frequency Analysis is intended to help prioritize hydrologic hazards at Reclamation dam sites and to help quantitatively assess hydrologic risks at specific dams. If results from a Preliminary Flood Frequency Analysis indicate that one cannot screen out the hydrologic risk at a dam site, additional studies would be the best approach to resolve the hydrologic issue. In addition, if there are significant economic or loss of life issues, additional work may need to be conducted to refine the results of the preliminary study.

Dams that do not pass the PMF and are not already slated for a higher level study can be prioritized for hydrologic hazards by using the following categories:

Low priority (Issue should be revisited at next CFR)
Action recommended before the next CFR
Action recommended in the next 2 years
Action required this FY
Immediate action required

The following scenarios provide an example of how the Preliminary Flood Frequency Analysis can be used to assess hydrologic risk at a particular dam and to develop recommended actions based on the assessed hydrologic risk. Figure 3 provides an illustration of the three scenarios. The Preliminary Flood Frequency Analysis provides this information and is a good place to begin when assessing hydrologic risk. Peak discharge will be one of many variables that may need to be considered when assessing risk. In many cases, other factors will need to be considered in addition to the peak discharge estimate. In these cases, the following example is a good starting point, but may be too simplified as the Senior Engineer considers other factors that are important in hydrologic hazards. The Flood Hydrology Group (D-8530) is currently in the process of developing appropriate tools that can be used to address hydrologic issues other than peak discharge.

Compare the total discharge capacity to the peak discharges of the frequency curve for the following three scenarios:

Scenario (A): Upper curve does or does not intersect spillway capacity.
Middle curve does not intersect spillway capacity.
Lower curve does not intersect spillway capacity.

INTERPRETATION
In this case, the spillway appears to be capable of handling an extreme event. The flood hazard is considered to be low for this scenario. Therefore, this case should be a low priority. See Section 3.1.3 if problems are encountered when the upper curve does not extend to the 10,000-year return period in a Preliminary Flood Frequency Analysis.

SUGGESTED RECOMMENDATION
Hydrologic issues should be revisited during the next CFR.

Scenario (B): Upper curve intersects spillway capacity.
Middle curve intersects spillway capacity at >500 years.
Lower curve does not intersect spillway capacity.

INTERPRETATION
In this scenario, the spillway can probably safely pass floods of frequent return periods; however, it is uncertain whether the spillway can safely pass floods greater than a several hundred-year return period. This case encompasses dams that potentially have a wide range of flood hazards. The flood hazard for each dam in this category will depend on the return interval at which the middle curve intersects spillway capacity and the consideration of other factors such as consequences and surcharge volume. Further study is recommended to determine the actual level of flood hazard for dams which are identified as having the greatest flood hazard in Scenario (B).

SUGGESTED RECOMMENDATION
For these dams, action should be taken within the next two years or before the next CFR to better define hydrologic hazards. Discuss with the Manager, D-8530 and appropriate staff to determine the scope of the problem and course of action.

Scenario (C): Upper curve intersects spillway capacity.
Middle curve intersects spillway capacity at <500 years.
Lower curve does or does not intersect spillway capacity.

INTERPRETATION
In this case, the spillway is not capable of handling a moderate to high probability event. The flood hazard is high for this scenario. If other factors, such as surcharge volume and consequences also point to high flood hazard, more study is imperative to determine the risk due to floods. Figure 1 is another example of this scenario.

SUGGESTED RECOMMENDATION
Action should be taken this FY or next FY to address hydrologic concerns with consideration of other factors discussed in the next paragraph. Discuss with the Manager, D-8530 and appropriate staff to determine the scope of the problem and course of action.

The Preliminary Flood Frequency Analysis only addresses one component of flood hazards, the peak discharge estimate. It may also be necessary to calculate flood volumes when assessing flood hazards at Reclamation dams. If the peak discharge does not safely pass through the spillway and other combined outlets, as in Scenarios (B) and (C), it may be that the preliminary peak discharge estimates are too conservative. It is also possible that the spillway and reservoir surcharge storage may have been designed to store the flood volume and a hydrograph is needed to address the issue.

<u>3.2 Differentiating between peak data and volume data</u>

During any flood, the peak discharge is the highest point on the flood hydrograph (Figure 4). The flood volume is the total amount of water produced by the flood and is equal to the integrated area under the hydrograph for a specified duration. The shape of the hydrograph may differ greatly depending on the cause of the flood; therefore, the volume may vary for floods that have the same peak discharge estimate. The Preliminary Flood Frequency Analysis provides only estimates for the frequency of peak discharges. It does not include, nor imply, any information regarding the frequency of flood volumes and should not be used for this purpose. The Flood Hyrology Group (D-8530) is currently in the process of developing tools that can be used to provide simplified hydrographs for the CFR process. It is anticipated that it will take several years before this can be widely applied.

3.3 Comparing flood frequency information with the PMF

Although new probabilistic flood estimates may help to place the PMF in context, they are not directly comparable to the PMF. Although currently the PMF may be considered as an upper limit for safety determinations in the CFR process, it is important to understand that the PMF is a deterministic estimate of the hydrologic loading and that the probability of this loading cannot be determined. It is possible that the probability of occurrence of 50% of the PMF at one dam is equivalent to the probability of occurrence of 75% of the PMF at another dam. It is recommended that judgements for Reclamation dams be made from probabilistic information from the Preliminary Flood Frequency Analysis and any other risk-based analyses in keeping with Dam Safety's move to Risk Analysis.

3.4 Tools for calculating an inflow volume for the reservoir for a particular flood

The flood frequency analysis only provides estimates of peak discharge from the flood frequency curve and therefore cannot be used to calculate an inflow volume for a particular flood. Hydrographs are necessary for this task and will need to be developed if inflow volumes are required. See the discussion regarding peak versus volume data in Section 3.2 for further clarification.

3.5 What to do if the Preliminary Flood Frequency Analysis is the only information available for a Risk Analysis

Use the Preliminary Flood Frequency Analysis as a preliminary indicator of hydrologic hazards for the site of interest. If the information from the Preliminary Flood Frequency Analysis does not meet Tier I or Tier II guidelines, a more detailed flood study should be conducted.

3.6 Resolving hydrologic issues at sites with no paleoflood information

For many Reclamation dams, at-site and regional paleoflood information have yet to be collected. In these cases, the engineer should use the preliminary flood frequency curve as it is drawn based on regional and/or at-site historical information. The curve generally extends to a 500-year return period. In many cases, a curve extending only to the 500-year return period may not be very useful for assessing the long-term flood hazard. In these cases, it is recommended that paleoflood information be collected. Staff in the Flood Hydrology Group are currently evaluating a technique new to the Preliminary Flood Frequency Analysis that can be used when paleoflood information is not available or cannot be collected before the CFR due date. Reconnaissance-level paleoflood information is being gathered on an ongoing basis. A database of paleoflood and hydrologic information for use in the CFR Process is currently being developed; as more information is collected, this database will become more complete.

3.7 Meeting Tier I Guidelines beyond 1:10,000 years

Some Reclamation dams may have the potential for high loss of life if the dam should fail during a flood. In some cases, Tier I guidelines are not met at the 10,000-year return period. Although there is not an established procedure for extending the frequency curve beyond the 10,000-year return period, staff from D-8530 are willing to work with the Senior Engineer to determine the best approach.

3.8 How to proceed with getting more hydrologic information

If any questions arise in the CFR Process or if there are recommendations following the CFR to assess flood hazards, please inform the Manager of the Flood Hydrology Group (D-8530) as soon as possible in order to discuss flood hydrology-related issues and outline a scope of work.

4.0 REFERENCES

England, J.F., Jr., Klinger, R.E., Camrud, M., and Klawon, J.E., 2001, Guidelines for Preparing Preliminary Flood Frequency Analysis Reports for Comprehensive Facility Reviews, Version 1.0: Bureau of Reclamation, Probabilistic Flood Hazard Cadre, 10 pp.

Interagency Advisory Committee on Water Data (IACWD), 1982, Guidelines for determining flood flow frequency: U.S. Interagency Advisory Committee on Water Data, Hydrology Subcommittee, Bulletin 17-B (revised and corrected), with editorial corrections, dated March 1982, 28 p. and appendices.

U.S. Bureau of Reclamation, 1999, A Framework for Characterizing Extreme Floods for Dam Safety Risk Assessment: Prepared by Utah State University and Bureau of Reclamation, November 1999, 67 p.

Figure 1. Example Completed Preliminary Flood Frequency Curve

(A)Frequency Distribution and confidence intervals; (B)Regional peak discharge data (hachured box); (C) Paleoflood data (shaded box); (D) Middle preliminary flood frequency curve; (E) Upper preliminary flood frequency curve; (F) Lower preliminary flood frequency curve

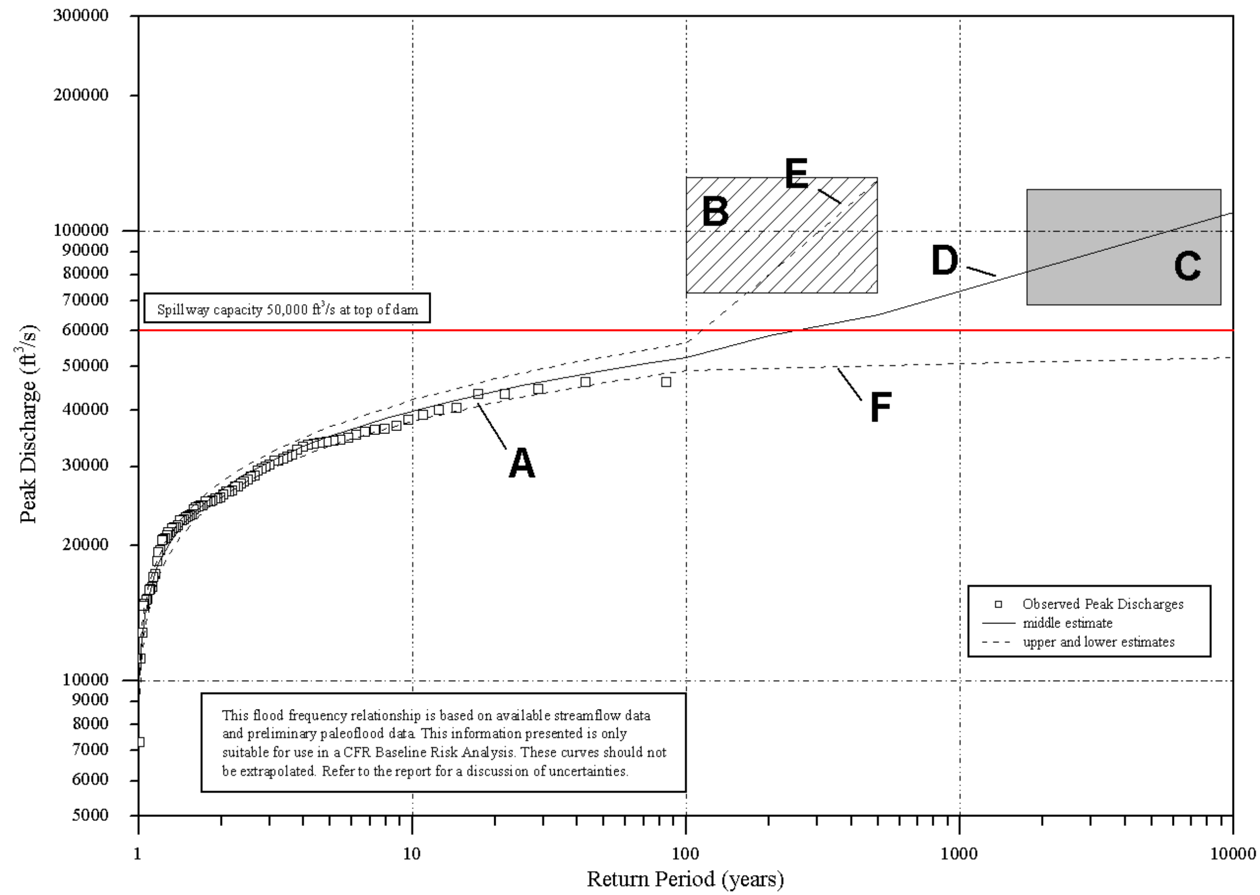
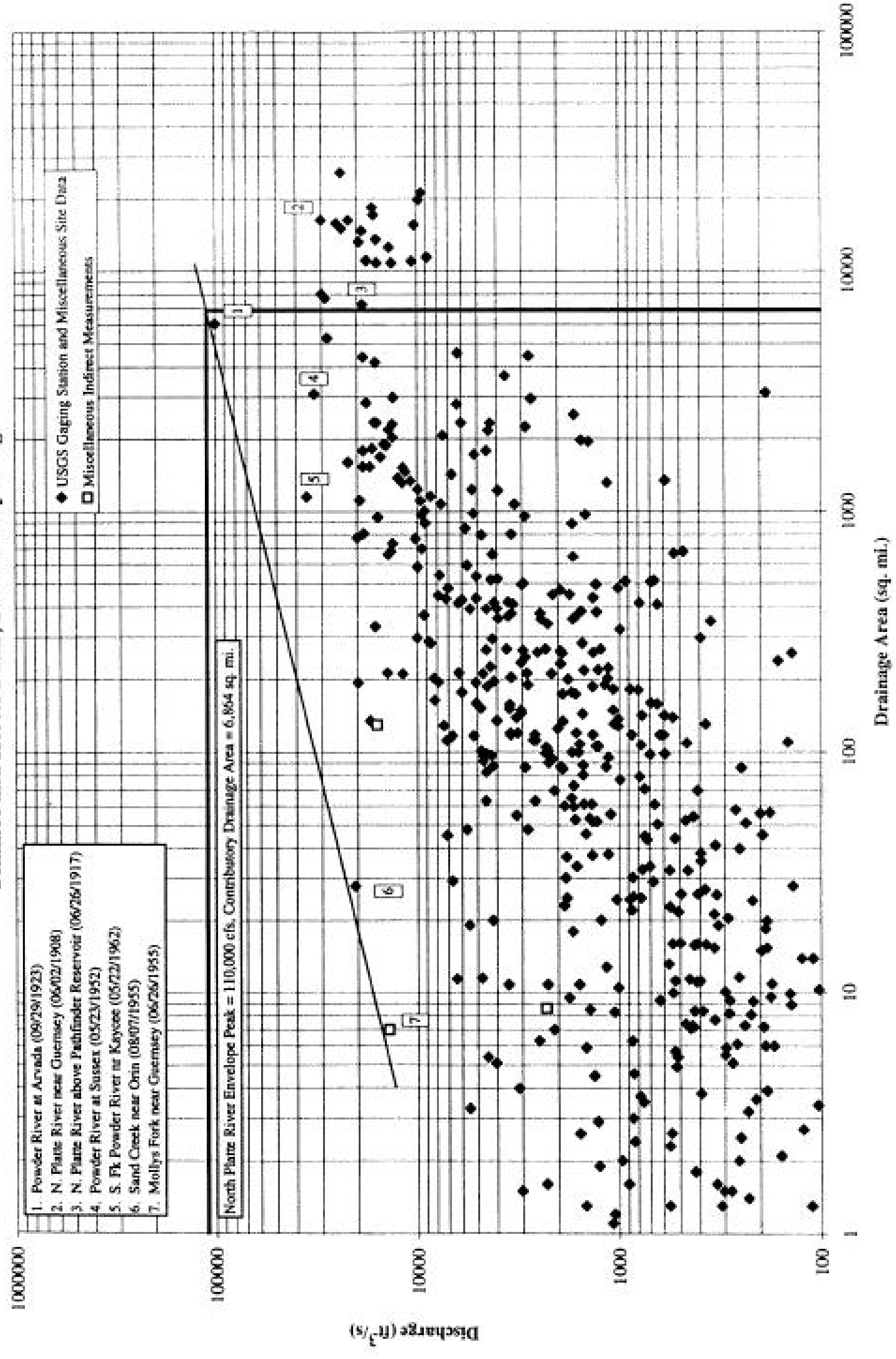


Figure 2
PEAK DISCHARGE ENVELOPE CURVE
Seminoe and Kortes Dams, Southern Wyoming



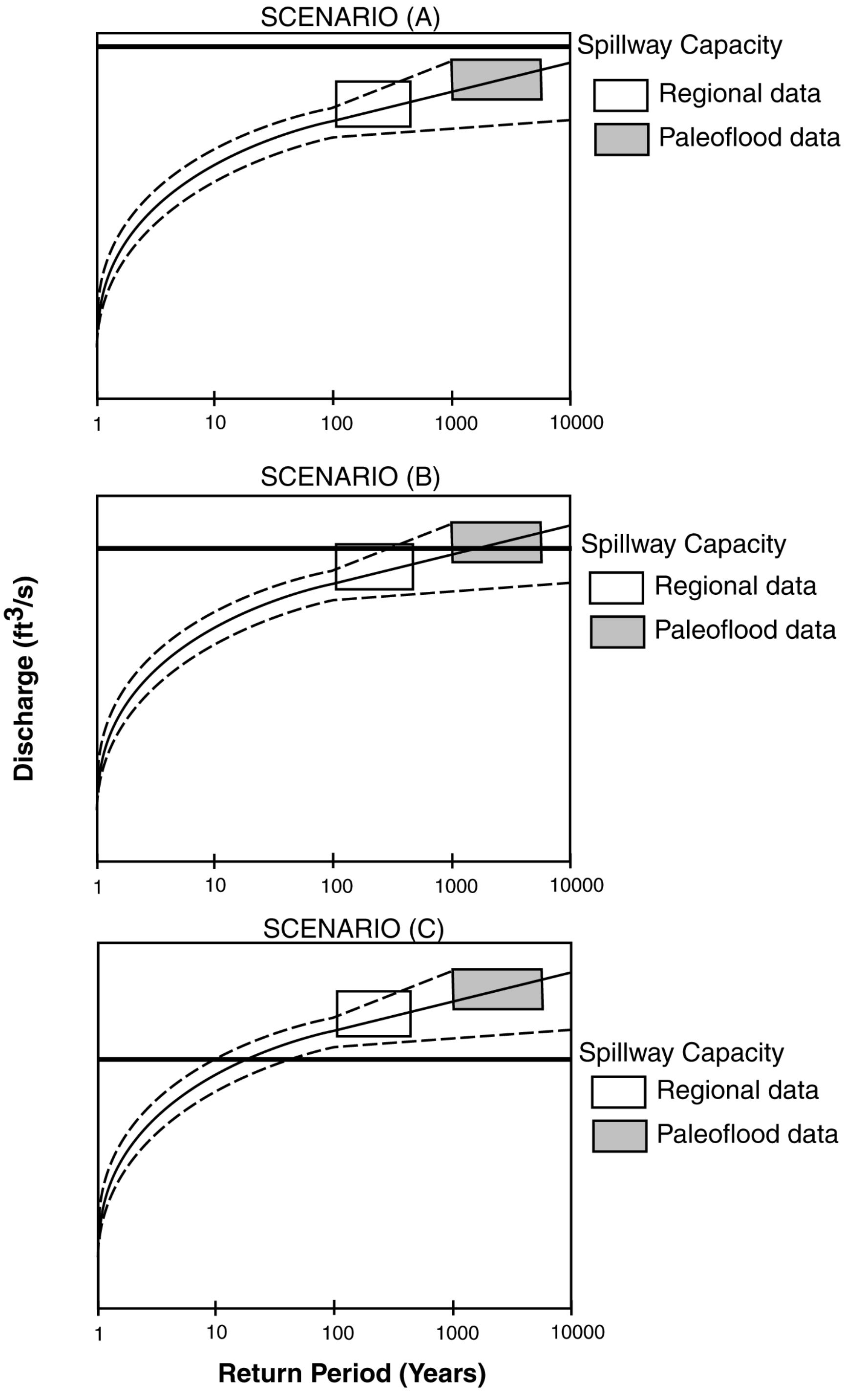
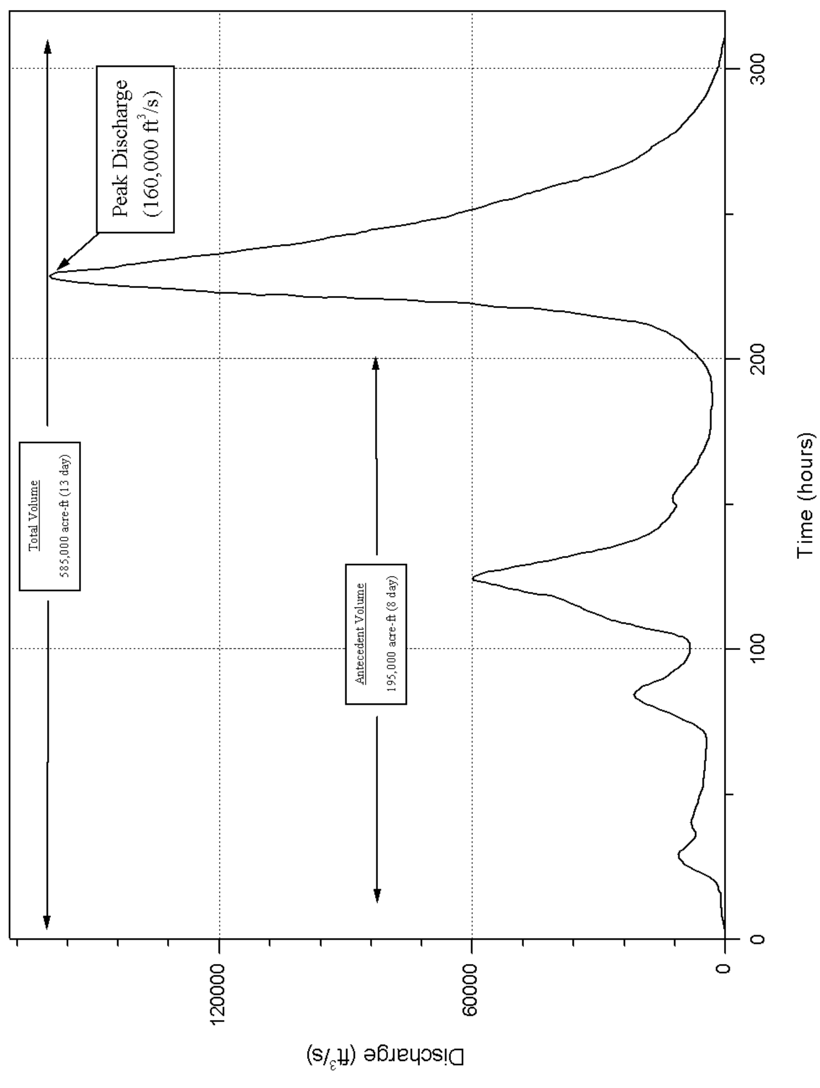


Figure 3. Schematic of case scenarios for interpretation of the flood frequency curve

Figure 4. Example Hydrograph



Attachment 2

Sample Event Tree for Hydrologic Failure Modes

APPENDIX H - EXAMPLE HYDROLOGIC EVENT TREE

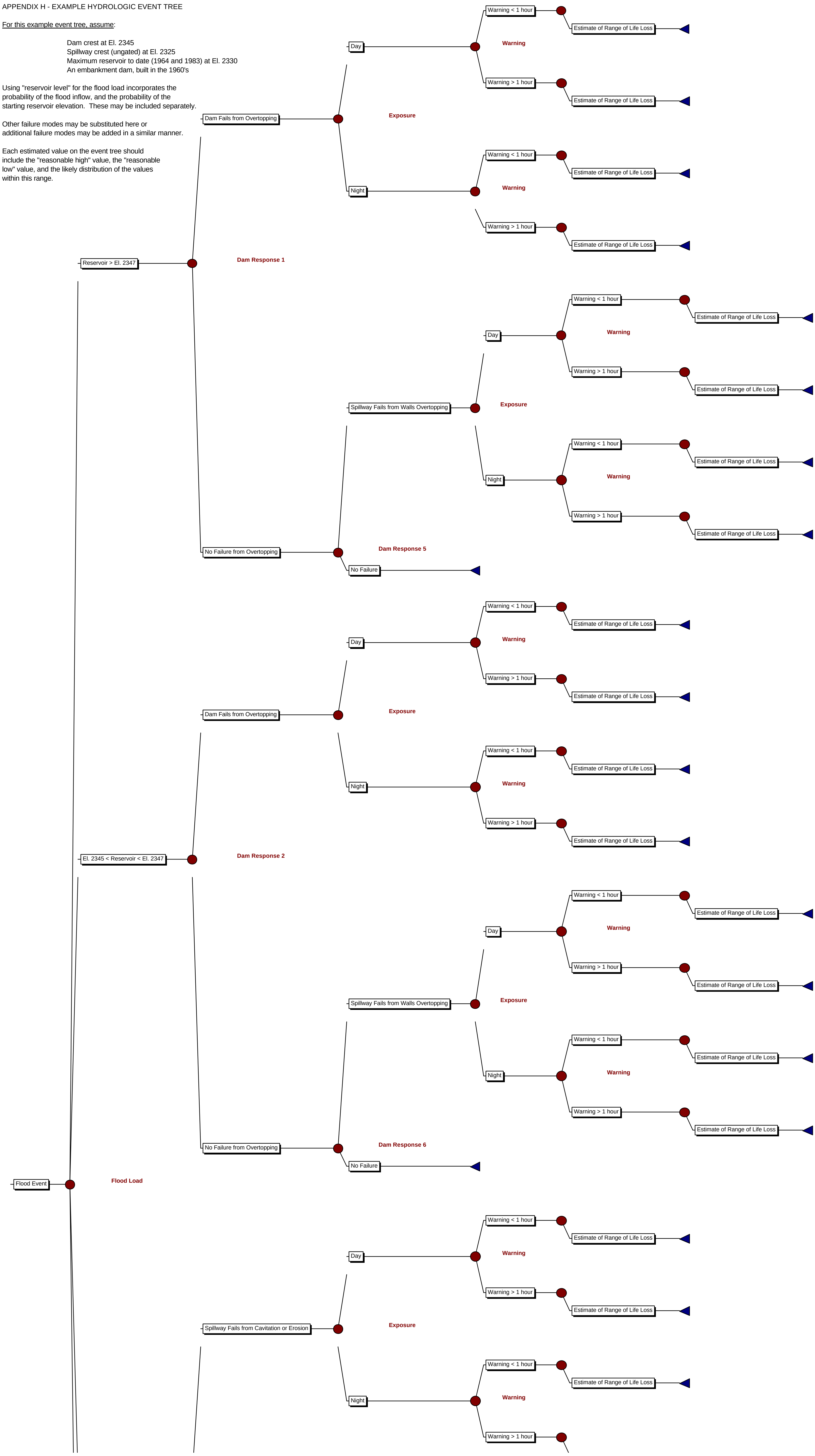
<u>For this example event tree, assume</u>:

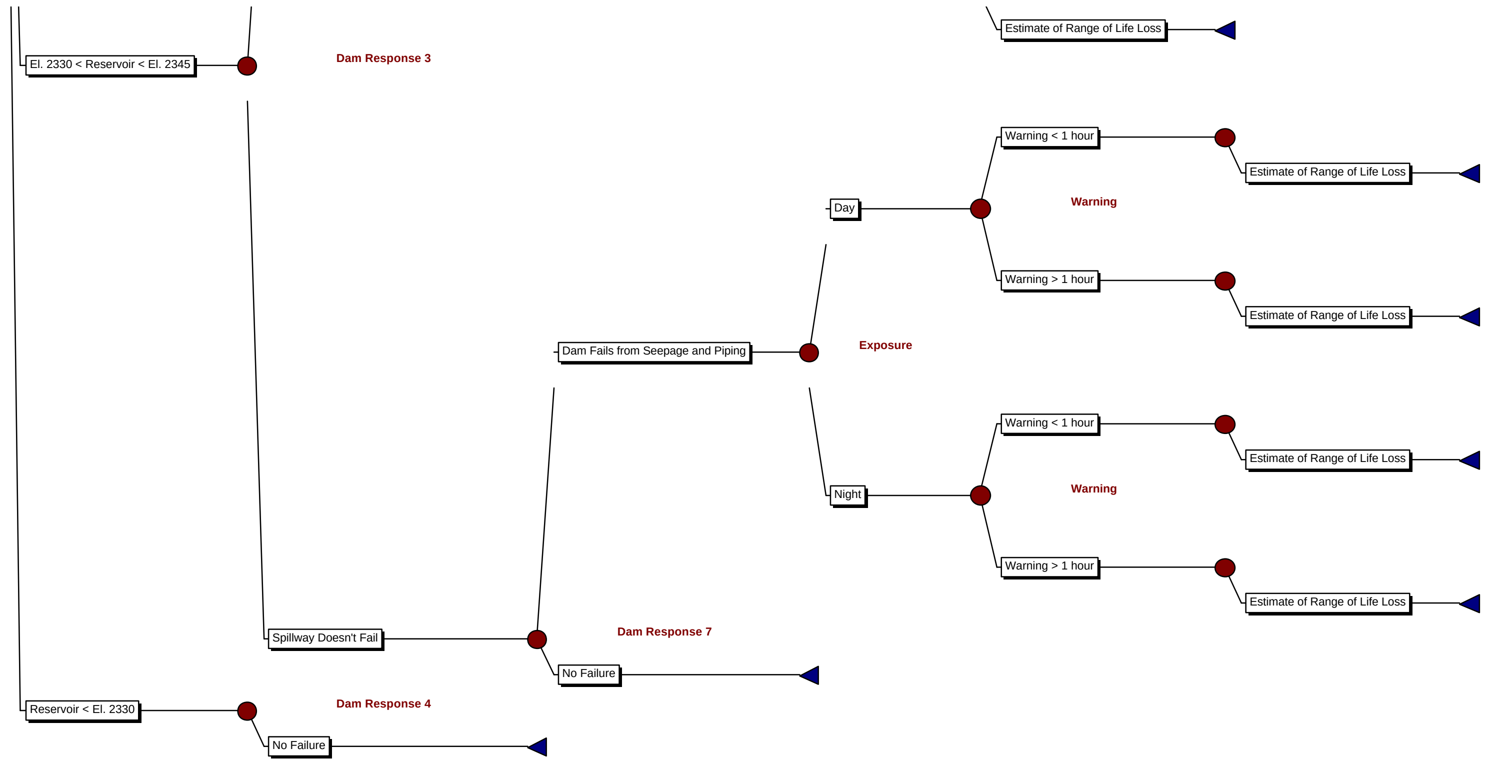
Dam crest at El. 2345
Spillway crest (ungated) at El. 2325
Maximum reservoir to date (1964 and 1983) at El. 2330
An embankment dam, built in the 1960's

Using "reservoir level" for the flood load incorporates the probability of the flood inflow, and the probability of the starting reservoir elevation. These may be included separately.

Other failure modes may be substituted here or additional failure modes may be added in a similar manner.

Each estimated value on the event tree should include the "reasonable high" value, the "reasonable low" value, and the likely distribution of the values within this range.





Estimate of Range of Life Loss
El. 2330 < Reservoir < El. 2345
Dam Response 3
Warning < 1 hour
Estimate of Range of Life Loss
Day
Warning
Warning > 1 hour
Estimate of Range of Life Loss
Dam Fails from Seepage and Piping
Exposure
Warning < 1 hour
Estimate of Range of Life Loss
Night
Warning
Warning > 1 hour
Estimate of Range of Life Loss
Spillway Doesn't Fail
Dam Response 7
No Failure
Reservoir < El. 2330
Dam Response 4
No Failure